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APPLICATION OF SCHEDULING HEURISTICS
TO THE AIRCRAFT MAINTENANCE DEPOT

THESIS

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APPLICATION OF SCHEDULING HEURISTICS TO THE AIRCRAFT MAINTENANCE DEPOT

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science

by

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Preface

The idea of applying scheduling heuristics to an aircraft maintenance depot was offered by my thesis advisor, Lt. Col. Thomas Clark. He suggested using a model already developed by two of his former students, Captain David Walker and Captain Philip Miller, at Warner Robins Air Logistics Center. Information and insight gained about the operation of an aircraft depot were the result of subsequent visits to the depot.

Special thanks are due to Captain Philip Miller, who was always eager to respond to questions and offered invaluable assistance. Of course, I would like to thank Lt. Col. Thomas Clark for his patience and guidance throughout this endeavor.

Joseph W. Adams

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Abstract

Scheduling heuristics were applied to a model of the aircraft maintenance depot at Warner Robins Air Logistics Center. Since the C-141 aircraft was being overloaded into the depot, heuristics which gave the C-141 priority were tested in an effort to reduce the mean and variance of the distribution of times the C-141 aircraft spent at the depot. One heuristic was found which reduced the average depot time by 4%. The significance of this decrease was calculated to be 91%. A similar heuristic reduced the variance by 81%, with a significance of 100%. Thus, the potential exists for improving the flow of the overloaded C-141 aircraft through the depot, using scheduling heuristics.

APPLICATION OF SCHEDULING HEURISTICS TO THE AIRCRAFT MAINTENANCE DEPOT

I. INTRODUCTION

Introduction

An analysis of scheduling for depot level maintenance of USAF aircraft at Warner Robins Air Logistics Center is presented in this thesis. The analysis is directed towards providing the production manager at the depot with scheduling rules that will assist in achieving maximum utilization of the depot facilities. The analysis involved development of a Q-GERT network model. The model can provide the schedulers, who program aircraft through the depot for the using commands, with more realistic estimates of the depot's production capacity and the time required by invididual aircraft for depot level repair.

Depot utility is a measure of the benefit the Air Force derives from the operation of the depot facilities. As the time an aircraft spends in depot repair is decreased, the time the aircraft is available to the using command is increased. If the quality of work done at the depot remains constant of the decrease in depot time, the depot utility will have increased. Since scheduling rules affect only the order in which aircraft are serviced and not the service itself, quality of work was assumed independent of any scheduling rules that may be applied at the depot. Refer to Chapter II for a further explanation of depot utility.

Three different types of aircraft use the depot facilities at Warner Robins, and the extent to which these facilities are utilized is a function of the mean and variance of the probability distribution of the time spent at the depot for each aircraft type. This relationship is demonstrated in the equation:

$$\text{Depot Utility} = U(\mu_1, \sigma_1^2, \mu_2, \sigma_2^2, \mu_3, \sigma_3^2)$$

The utility function is simply a means of determining the preference of one set of means and variances versus another. Since many of the facilities that are common to all types of aircraft at the depot, have associated with them a waiting time, total time spent at a particular facility by an aircraft will depend upon the demand of the facility by all other aircraft. Thus, the means and variances of the probability distribution for each type of aircraft are interdependent. For example, specific scheduling changes made to reduce the mean for aircraft of type A, may result in a corresponding increase in the means of aircraft types B and C. The utility function is necessary to determine whether such a change is beneficial. For different loading of aircraft into the depot and for each type of scheduling rule employed to determine the order in which waiting aircraft will use busy facilities, there will be a unique set of means and variances and correspondingly a unique level of utilization. Thus for these different loadings of aircraft into the depot, the production manager must know which scheduling rules to employ to maximize utility.

Examining the effect of various scheduling rules on the operation of the depot using a model of the depot implies the use of simulation. Shannon defines simulation as "the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behavior of the system or evaluating various strategies." (Ref. 20:2) There are two important features of a model constructed using the Q-GERT language. These are flow and flow time. In the model, every arriving aircraft is processed through the system by completing all necessary service activities. The flow of an aircraft refers to

the number and sequence of these activities that are performed upon it. The system flow time refers to the total time spent in the system. The times necessary for each class of service activity are fitted to some type of probability distribution. Service times for a specific aircraft are randomly drawn from these distributions. In this way service times are said to be stochastic. Of course, a portion of the system flow time will represent time spent by an aircraft waiting for a busy server to become available. When several such aircraft are waiting for the same server, some type of dispatching rule, also known as a queue discipline, must be employed to determine the order of service. These dispatching rules are the scheduling rules that will be tested upon the model.

When the depot process is modeled as a network of queues with stochastic service times, the continuous long term nature of the process can be evaluated. As the model simulates several months of the depot's operation, statistics are gathered measuring average waiting and service times for each server in the system. These statistics can provide the scheduler with more realistic estimates of the flow times upon which to base due dates and plan further arrivals. More importantly, these statistics measure the effect of any scheduling rules applied to the system and are the means of illustrating the potential for increasing total utility for a variety of aircraft loadings at the depot. Such scheduling rules, hereafter to be called heuristics can also be based on due date information from the schedulers or even the history of an individual aircraft. Statistics gathered over a range of heuristics can provide insight and understanding into the relationships among service times, waiting times and loading of aircraft at the depot.

The following discussion of the activities performed at the depot will compliment the introduction of the model and clarify the structure of that model. The depot at WRALC is responsible for programmed depot maintenance (DPM) and analytical conditioning inspections (ACI) of both the C-130 and C-141 aircraft as well as technical modifications done on the F-15. In addition, aircraft of the above three types requiring miscellaneous depot level repairs, use the facilities. Both PDM and ACI are an intensive series of structural and functional tests and repairs performed upon the body of each aircraft. The steps associated with PDM and ACI are identical except the structural inspection is expanded during an ACI. The entire depot process is represented in the structural diagram of figure 1. The PDM or ACI portion of the process is shown in figure 2.

Apart from the PDM portion of the depot process, most of the facilities including those performing paint, depaint, and fuel system work are common to all aircraft types. This provides the production manager with the opportunity to assign a higher priority to an aircraft type when the depot is overloaded with that type due to delays in the PDM portion of the process or to a sudden increase in the input rate of that aircraft type. Of course, for such a scheduling heuristic to be successful, the set of means and variances obtained after its implementation would have to yield a higher utility than the preheuristic set. Then, the success of the heuristic implies that the reduced priority of other aircraft types at the common facilities does not increase their mean and variance enough to produce lower utility.

Assuming that the depot experiences overloads in only one aircraft

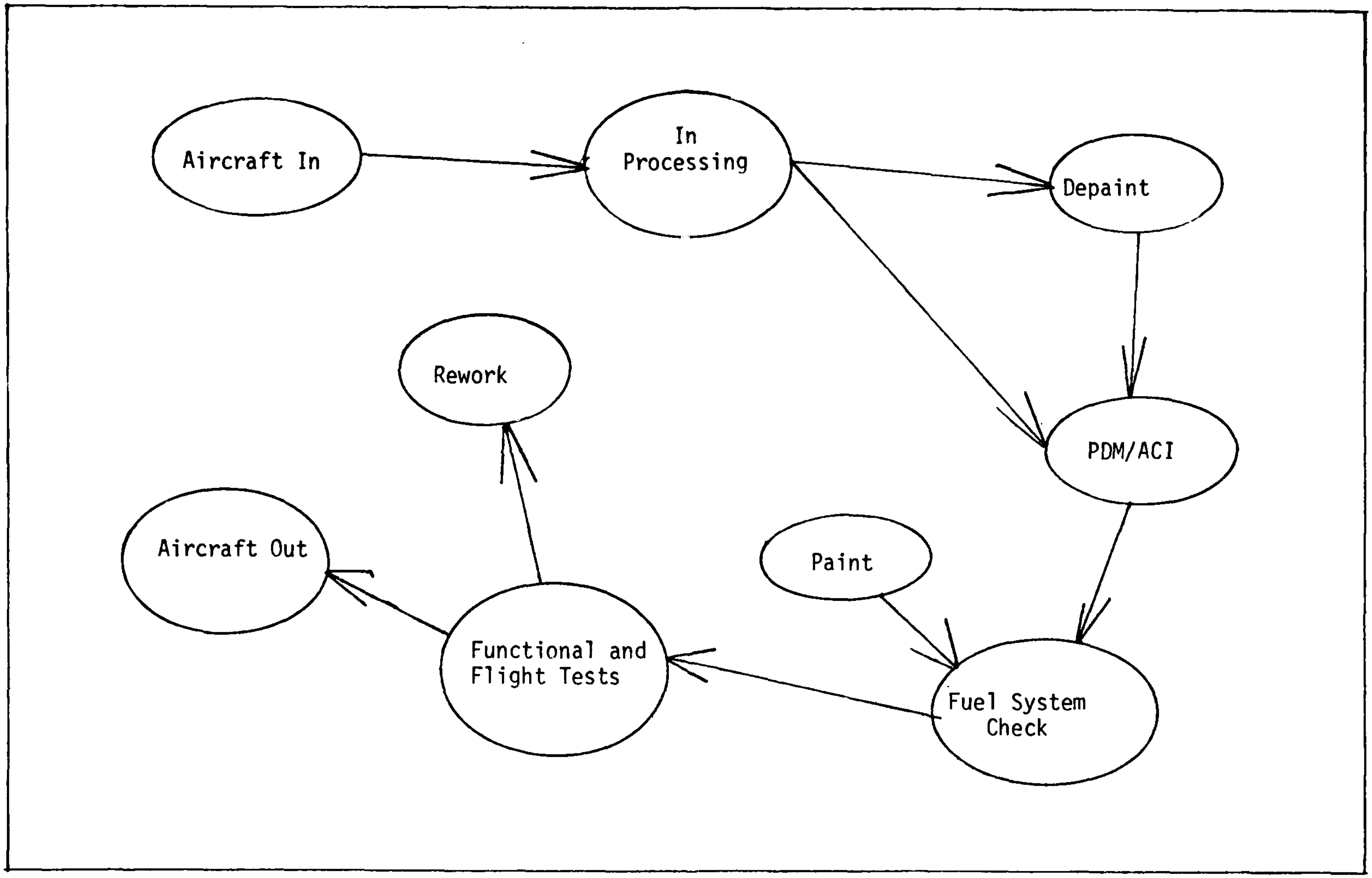

Fig. 1. Structural Diagram of the Depot Process

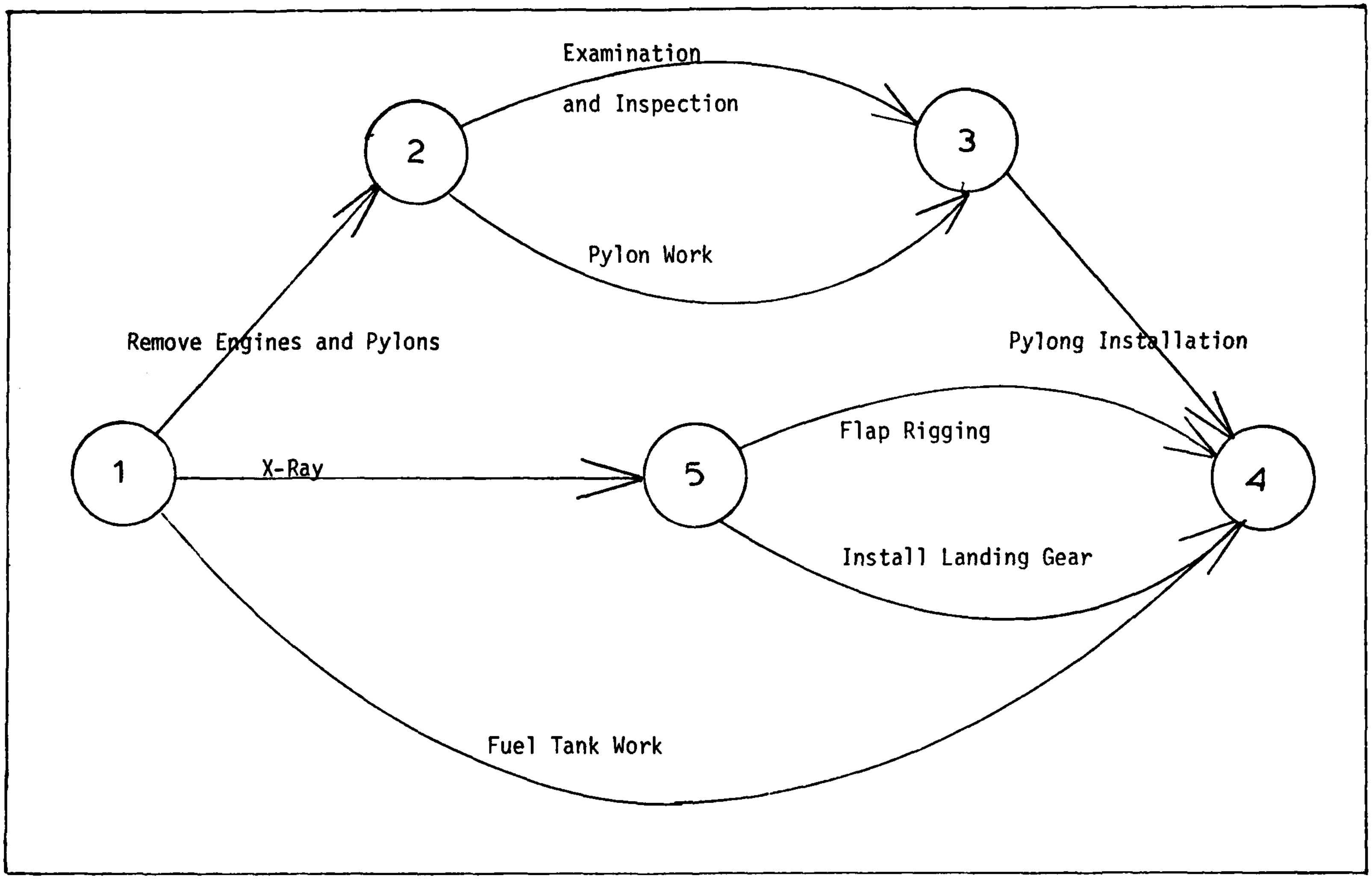

Fig 2. PDM/ACI Portion of Depot Process

at a time, the heuristic just discussed will have the effect of reducing change in the mean time at the depot due to an overload. Thus the variance for each type over a period of a number of such overloads will be less than variance obtained without the heuristic. Thus the schedulers can plan arrivals over an extended period with greater confidence when such a heuristic is employed. This type of heuristic will be of primary concern in this thesis.

Statement of Problem

The potential for increasing depot utility at Warner Robins Air Logistic Center by employing scheduling heuristic is not being considered.

Research Objectives

The objective of the research done in this thesis is to find scheduling heuristics that can be used by the production manager to maximize utility at the depot for different combinations of aircraft loaded into the depot. The heuristics tested will be a variety of priority dispatching rules which determine the order in which aircraft will use the limited resources available.

Since no formal utility function exists, the set of means and variances obtained for different heuristics will be presented to demonstrate the options available to AFLC. Of course, lower means and variances are preferred for each aircraft type.

General Methodology

The Q-GERT language is especially suitable for the testing of priority dispatching rules. Many scheduling heuristics can be easily applied to all queues in the model. These queues are representative of the points where the production manager must make resource allocation decisions. One type

of heuristic to be employed at queues representing common facilities has already been discussed.

Since the C-141 aircraft currently is experiencing more substantial delays than the D-130 or F-15 the greatest potential for increasing depot utility is expected to exist by the assignment of priority to the C-141 aircraft. The scope of the testing will be limited to manipulation of the C-141 within the context of the entire system.

Overview of Thesis

Chapter II of the thesis will acquaint the reader with the concepts of job shops, utility functions and heuristics. Presented in Chapter III will be the model and the heuristics to be applied in substantial detail. Chapter IV will follow with a analysis of the experimental results and the conclusions which follow from these results.

II. BACKGROUND

Introduction

This chapter acquaints the reader with the concepts of utility functions, job shops and scheduling heuristics and applies them to the maintenance depot.

Depot Utility

Utility functions are generally associated with decision analysis. The depot utility function illustrates the case where each of the decision maker's alternatives has associated with its several outcomes known as attributes (Ref. 11:23). In the depot case, each mean and variance represents an attribute associated with a specific scheduling rule. Each set is an alternative. The decision maker must choose an alternative on the basis of this set of attributes. The utility function based on the decision maker's preference transforms each set of attributes into a single value for the purpose of comparing alternates.

If the decision maker's preference for the value of a single attribute is independent of the values of all other attributes, the utility function can be simplified. The simplified function is the weighted sum of the utilities of the attributes. The utility curve of each attribute is found by having the decision maker rank all possible outcomes between values of zero and one. The decision maker must then weight each attribute type by deciding upon its relative importance to the decision. Applying this technique to the depot utility equation yields:

$$\bar{U} = \lambda_1 U_1(\mu_1) + \lambda_2 U_2(\sigma_2^2) + \lambda_3 U_3(\mu_2) + \lambda_4 U_4(\sigma_1^2) + \lambda_5 U(\mu_3) + \lambda_6 U(\sigma_3^2)$$

where U_i = Utility function (curve) of attribute i

λ_i = weighting of attribute i

$\sum \lambda_i = 1$

Whether the independence assumption is valid in the depot case is beyond the scope of the thesis. However, even the equation demonstrating this simplified case indicates the difficulty involved in actually obtaining such an equation. Transforming the concept of readiness and depot capability into a series of utilities and weights is very complex. The inputs are numerous and varying. The contribution of each aircraft to a command's readiness, in addition to the commands contribution to USAF readiness, must be considered.

In industry, where marketable products or intermediates take the place of aircraft, a simple dollar value can be placed on each product. Here, scheduling rules are used to maximize utility which represents profit. Such types of industrial operations resembling the operations of the depot, are termed job shops. The next section introduces the concept of a job shop and its applicability to the depot.

Job Shop Environment

The job shop process is characterized by a series of jobs, each composed of a unique series of activities, which must be scheduled through the shop by the assignment of single activities to individual machines (Ref. 4). Since each series of activities associated with a job must be performed in a predetermined sequence, activities cannot be assigned irrespective of the job they are part of. Thus before an activity associated with some job can be started, the proper machine must be available and all previous activities must have already been performed. For a given set of jobs, linear programming may be used

to find the optimal assignment of activities. Optimality is defined by the user and usually corresponds directly with utility or profit. This type of scheduling problem is termed static since the set of jobs remain constant.

The more common type of problem encountered in a job shop environment is where jobs are continually arriving at the shop. This type is known as a dynamic scheduling problem. Solutions which view the dynamic problem as just a series of static problems are not only computationally impractical, but also ignore the stochastic nature of a continuous process. (Ref. 2) Therefore, just as in the depot, such systems are modeled as a system of queues with stochastic arrival and service times. The flow of jobs through such a model must correspond to the proper sequence of activities that make up the jobs. Flow for different jobs can be modeled both probabilistically and deterministically.

Scheduling heuristics can be applied to such a model in order to find the operating conditions that provide the user with the greatest utility or profit. The next section discusses the different types of heuristics that can be applied to such models. In addition, the results of other research dealing with scheduling heuristics will be reviewed.

Scheduling Heuristics

The Heuristic Approach. A heuristic is any systematic method for solving problems. (Ref. 22) In the case of the job shop, a heuristic is the proper scheduling rule for a given system state such that a desired level of utility is maintained. The state of the system is defined by the set of jobs awaiting service in each queue in the system. Since the number of system states is infinite, it would be impractical to have and apply a unique heuristic for every system state. Instead system states

are grouped in some manner so that one heuristic applies to an entire group of system states. For example, group A may represent all system states such that the number of jobs in the arrival queue is between A_{min} and A_{max}.

Thus the heuristic approach defined by the systematic application of heuristics based on a grouping of system states, does not provide an optimal solution all the time. However, depending on the breakdown of the system states, the heuristic approach does provide a consistent, near optimal solution which maintains a desired level of utility with a minimum amount of computational effort. (Ref.22)

Types of Heuristics

It should be clear from previous sections that the number of possible heuristics is only limited by the experimenter's imagination. In addition, their possible classifications are almost as numerous. However, classifying a heuristic as either static or dynamic is useful and important. A heuristic in which a job's priority in a queue does not change once assigned is considered a static heuristic. When a job's priority can change, the heuristic is considered dynamic. (Ref. 2) The first-come-first-serve heuristic is an example of a static type. The shortest-operating-time heuristic is an example of the dynamic type. A new job having the shortest expected service time would immediately be given highest priority while the priority of the remaining jobs is decreased.

The best guide to choosing types of heuristics to test on a particular system, is a good working knowledge of that system combined with a familiarity of the heuristics most commonly used. (Ref. 15) Below is a list of the common types presented in the literature along with a brief description of each.

1. First-Come-First Serve (FCFS) - Priority only depends on time job entered queue.

2. Shortest Operating Time (SOT) - Requires an estimate of the service time for each job in the queue. If the queue length is always greater than zero, the longest job may never be serviced.

3. Static Slack (SS) - SS is equal to due date minus time of arrival. Thus external scheduling information is needed to assign priorities. Job with least expected time in the system is given highest priority in each queue.

4. First in System, First Served (FISFS) - Highest priority is given to job which entered system first.

5. Last-Come-First Serve (LCFS) - Most recent entries into system are given highest priority.

6. Dynamic Slack (DS) - DS is equal to time remaining till due date minus remaining expected flow time. Job nearest due date and requiring must work is giver ' jhest priority. (Ref. 22)

The usefulness of any of these heuristics depends on the level of utility achieved by its application. In addition, if a heuristic is found to be useful, the user must determine the range of usefulness. The next section reviews the success of former research of the application of heuristics to job shop scheduling problems.

Former Research

The SOT rule was of primary concern in early research of complex network systems since studies with single server systems had shown that the rule produced the best results in terms of minimizing flow time. (Ref. 21)

In 1963 Nanot tested ten heuristics including the six listed in the last section, using six different job shop structures. Again the SOT rule performed the best, giving a minimum flow time. (Ref. 17)

However, the rule did exhibit a relatively high variance which caused undesireable flow times for about 1% of the orders. Conway and Maxwell tried to eliminate this disadvantage by imposing limits on waiting times and by alternating the SOT rule with the low variance FCFS rule. (Ref. 3) Generally they found that there was a trade-off between variance and mean flow time.

Some studies have recognized that multiple criteria exist for evaluating results. These include percent of late orders, average waiting time, labor utilization, machine utilization, and others. The concept of multiple criteria closely corresponds with the concept of a utility function. LeGrande developed a job shop simulation model using six priority dispatching rules, judged on the basis of ten criteria. (Ref. 13) Again the SOT rule had the best overall ranking.

Berry has experimented with heuristics which take into account due date information (Ref. 1). He found the static rules of this type, where due dates did not change during the job's time in the system, out performed the dynamic rules where all external information was constantly updated.

Thus, former research indicates that the simple SOT rule exhibits the greatest potential for decreasing flow time but at the risk of higher variances. In addition, heuristics that employ external information, perform best when this information is not updated. Therefore, those heuristics requiring a minimum of state and external information usually out perform the more complicated types according to the literature.

Therefore, the SOT rule along with the simple heuristics for assigning priority to an aircraft type discussed in Chapter I, will be

tested upon the model. A detailed description of the model and the procedure for applying these heuristics will be presented in the next chapter.

III. THE MODEL AND THE APPLICATION OF HEURISTICS

The Model

The depot at WRALC originally was modeled using the Q-GERT simulation language by Captain David Walker and Captain Philip Miller in March of 1980 at Warner Robins. Captain Walker worked directly for the aircraft production section of the depot, while Captain Miller was with the engineering and planning section. Engineering and planning is responsible for the allocation of necessary resources to the depot. The main purpose of the model was to demonstrate the depot could be effectly modeled using computer simulation.

Description

A simplified flow diagram of the model is shown in figure 3. A more detailed Q-GERT flow diagram along with the program code is given in Appendices A and B. The flow of aircraft through the depot represented in figure 3 corresponds with the flow shown in the structural diagram of figure 1.

There are limits to the number of aircraft of each type that can be simultaneously serviced at the depot. The limiting factor is the available hanger space at the depot. Thus, the limitation is imposed irrespective of the type of services required by an aircraft. In figure 3 these limits are listed as resource constraints at the arrival queues. An aircraft which arrives when no resources are available, must wait until an aircraft of the same type departs and frees the hanger resource. There are also limits to the number of aircraft undergoing PDM/ACI and miscellaneous repair at any one time. The limiting factor in this case is manpower. In figure 3 these manpower resource limits are listed at the PDM/ACI and miscellaneous

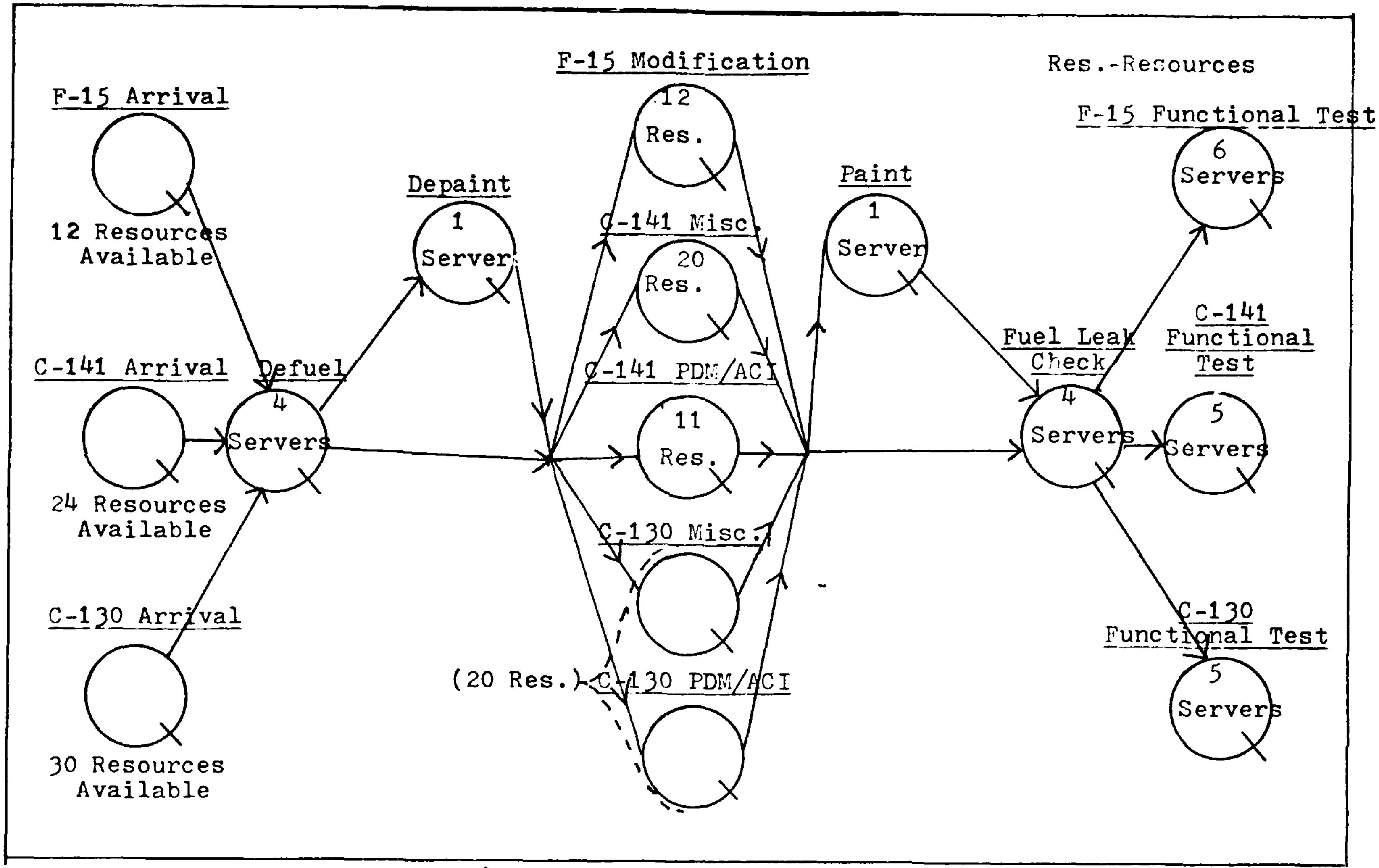

Fig 3. Flow Diagram of Model

repair queues for the C-130 and C-141 and at the F-15 technical modification queues.

Much of the branching in the model is determined by aircraft type. Since the model remembers the type of each aircraft in the system, this branching is said to be deterministic. Branching which controls flow to PDM/ACI or miscellaneous repair, and paint and depaint, is accomplished probabilistically. Probabilities for each branch are calculated using actual flow data from the depot. Service times at each queue are stochastic. However, there may be a separate distribution for each aircraft time at one queue.

Priority dispatching rules or heuristics are applied at the various queues in the model in order to specify the order in which waiting aircraft will use busy facilities. Note that no wait is necessary for an aircraft in the arrival queues or the PDM/ACI and miscellaneous queues unless the corresponding resource is not available.

PDM/ACI. The activities performed during the PDM/ACI portion of the depot process are shown in figure 2 of Chapter I. The original model did not break out this portion of the process. The author modeled the process based on information gained from two visits to the depot. The structure of this portion of the process differed from that of the depot model because certain activities in the PDM/ACI process can occur simultaneously.

Referring to figure 2, the number circles or nodes represent the start or end of one or more activities. Activities which start from the same node begin at the same time and thus occur simultaneously. However, before any such activities can begin at a node, all activities which end at this node must be completed. Thus the activity time between nodes

will correspond to the longest of the simultaneous activities. This type of system in which service times are stochastic can also be modeled using Q-GERT and was modeled separately. The model outputs the mean and variance for the PDM/ACI service time distribution. The purpose of the PDM/ACI model was as an aid in estimating total service time in this portion of the process for a specific aircraft so that the shortest operating time (SOT) heuristic could be employed. Times can be estimated for each activity in the PDM/ACI process based on the aircraft's former PDM time and the present condition of the aircraft. Inputting these times into the PDM/ACI model would result in an estimate of the total time required for PDM/ACI for a specific aircraft.

Verification and Validation. Verifying that the model behaves as intended involved analyzing each section of the model to ensure the depot conditions were being replicated. For example, ensuring that aircraft were indeed waiting at the paint facility when the facility was busy, and not being serviced simultaneously, was part of the verification process.

The degree to which the output from the model corresponds with the actual operation of the system is largely dependent on the data base and any assumptions made in the modeling process. The next section discusses the applicability of the data base and the effect of any assumptions.

Assumptions and Limitations. Six months of historical data were used to estimate the probability distribution for the service times and the branching probabilities. Service times were fitted to normal distributions except in the case of constant service time. The data base corresponds to a period where C-141 aircraft were being overloaded into the depot. Testing the model under different loading conditions may invalidate the

model.

Shortages of parts needed during the PDM/ACI process were not explicitly considered in the model. However, minor delays caused by such shortages were incorporated into the service time distributions. The type or rework required was not specified. Instead rework times were averaged for each aircraft and included in the functional test portion of the process.

Although the F-15 is painted and depainted at the same facilities as the C-130 and C-141, the facilities were modeled separately. There is sufficient space at the facilities for one C-141 and one F-15 or one C-130 and one F-15. Thus, service for the F-15 is independent of the service of the other two aircraft types.

Discussed in the next section are how, where, and why the heuristics chosen were applied to the model.

Heuristics

Whenever two or more aircraft are waiting for the same server to become available, some type of rule must be applied to determine the order of service. The heuristics to be tested are these scheduling rules which are applied at the queues in the model.

Base Case. The rule now used at the depot is the first in system first served (FISFS) rule. Thus aircraft are always serviced in the order they enter the depot. Results using the FISFS rule at all queues will be used as a basis of comparison for all other heuristics.

Heuristics Tested. Based on the literature review and the applicability of priority heuristics discussed in Chapter I, the author chose to test two types of heuristics. The first heuristic which is to be used at

queues representing common facilities, is a slight variation of the FISFS rule. Priority was assigned to an aircraft type, in this case the C-141, by adding a constant to the number of days aircraft of that type were in the system and then applying the FISFS rule. Thus, if a C-141 and a C-130 had actually entered the depot on the same day, the C-141 would always be served first since the model would conclude the C-141 had arrived first. The level of priority, which is the number of days added to the depot time of the C-141, can be increased simply by using a larger constant.

The SOT rule is used at the C-141 PDM/ACI queue in an effort to increase the flow of C-141 aircraft through this stage of the process. Since the average length of the queue is only about one, the problem of a large variance usually associated with the SOT rule is avoided.

The priority heuristics at varying levels of priority were applied to the paint and depaint queues and/or the fuel leak check queue with and without the SOT heuristic in effect at the PDM/ACI queue. This strategy is represented in Figure 4. The paint, depaint, and fuel leak check queues possessed the longest waiting times in the base case, and thus it was assumed the priority heuristic would have the largest impact when applied to these queues. Note that at greater than or equal to fifty five days, infinite priority is reached. That is, a further increase in the level of priority has no further effect upon the operation of the system. This behavior is explained in Chapter IV.

By applying the SOT and priority heuristics, the author hopes to demonstrate that a decrease in the C-141 depot flow time can be achieved. Presented in the next chapter are the results of the testing and the conclusion derived from those results.

Heuristic	No. of Days Priority Paint (P)	No. of Days Priority Depaint (D)	No. of Days Priority af Fuel Leak Check (F)	Use of SOT Rule at PDM/ACI (S)
Base	0	0	0	No
S	0	0	0	Yes
P,D+10	10	10	0	No
P,D+10,S	10	10	0	Yes
P,D,F+10,S	10	10	10	Yes
P,D+20	20	20	0	No
P,D+20,S	20	20	0	Yes
P,D,F+20,S	20	20	20	Yes
P,D+30	30	30	0	No
P,D+30,S	30	30	0	Yes
P,D,F+30,S	30	30	30	Yes
P,D+40	40	40	0	No
P,D+40,S	40	40	0	Yes
P,D,F+40,S	40	40	40	Yes
P,D+50	50	50	0	No
P,D+50,S	50	50	0	Yes
P,D,F+50,S	50	50	50	Yes
P,D+60	60	60	0	No
P,D+60,S	60	60	0	Yes
P,D,F+60,S	60	60	60	Yes

Fig 4 Heuristics to be Tested

IV. RESULTS, CONCLUSIONS AND RECOMMENDATIONS

Introduction

This chapter reports the results obtained from the application of heuristics to the model. The results are reported in terms of the mean and variance of the depot time distribution for each aircraft type. In addition, these results are compared with the results from the base case, and the differences are analyzed for their statistical significance.

The Results

The results of each combination of heuristics applied to the model are shown in Table I. Each set of results represents average statistics from thirty runs of the model, where each run represents one year's operation of the depot. The analysis of these results will consist of finding the heuristic or heuristics which has most improved the C-141 statistics and then noting any undesirable effects in the statistics of the other two aircraft. Note that priority is given to both the C-141 and F-15 aircraft at the fuel leak check queue. This change was made to prevent significant increases in the F-15 statistics which occurred during earlier runs when only the C-141 aircraft was given priority.

The largest decrease in the mean of the C-141 time distribution corresponds with the heuristics which assigns a 30 day priority at the paint, depaint, and fuel leak check queues and applies the SOT rule at the C-141 PDM/ACI queue. The larger the decrease in the mean, the larger will be the increase in C-141 depot capacity. The indicated decrease of 1.93 days in the C-141 mean corresponds to an increase of

Table I

Results of Heuristics Application

Heuristic	C-141 Mean	C-141 Variance	C-130 Mean	C-130 Variance	F-15 Mean	F-15 Variance
Base	55.49	39.19	30.49	6.75	43.22	9.61
S	55.19	36.72	30.14	7.73	41.66	5.57
P,D+10	55.10	29.59	30.63	8.29	42.16	6.15
P,D+10,S	54.56	27.25	30.60	6.30	41.69	5.02
P,D,F+10,S	55.07	22.18	30.87	3.96	42.62	7.18
P,D+2P	54.23	22.37	30.76	7.45	42.32	6.71
P,D+20,S	54.67	35.76	30.77	5.57	42.34	4.67
P,D,F+20,S	54.31	14.44	31.57	10.69	41.46	5.62
P,D+30	55.26	30.8	31.23	16.89	42.65	10.82
P,D+30,S	55.5	21.07	31.82	11.22	42.47	8.70
P,D,F+30,S	53.56	20.16	31.06	9.00	41.97	6.15
P,D+40	54.29	15.52	30.51	8.94	42.06	5.34
P,D+40,S	56.3	26.21	30.90	12.67	42.19	8.07
P,D,F+40,S	54.45	14.29	31.28	12.46	42.40	7.51
P,D+50	56.18	27.67	32.07	17.89	41.71	7.02
P,D+50,S	56.27	33.29	32.35	14.24	42.15	7.24
P,D,F+50,S	55.19	22.56	30.92	10.11	41.72	5.52
P,D+60	55.46	20.16	32.06	11.22	42.97	10.50
P,D+60,S	55.01	25.40	31.73	9.30	42.77	7.51
P,D,F+60,S	53.89	7.51	31.01	9.55	42.10	6.3

approximately 4% in the depot capacity. The significance of the 1.93 day decrease is discussed in the next section.

The largest decrease in the variance of the C-141 time distribution corresponds with the heuristics which assigns infinite priority at the paint, depaint, and fuel leak check queues and applies the SOT rule at the C-141 PDM/ACI queue. Schedulers can plan future arrivals with greater confidence when the variance is decreased. In this case, the variance has decreased 81% from the base case. In the base case a scheduler could be 95% confident that a C-141 aircraft would spend between 42.97 and 68.01 days at the depot. After applying the heuristic the range of the C-141 depot days becomes 48.41 to 59.37. Thus the interval drops from 25.04 to 10.96 days.

The only undesirable effect of either of these two best heuristics is a 1.6% increase in the mean and a 41% increase in the variance of the C-130 time distribution. Since the C-130 aircraft is the only type which spends no time waiting in the arrival queue, this increased variance should cause minimal problems for the schedulers. The F-15 aircraft statistics have actually improved for both heuristics. Since the F-15 aircraft was also given priority over C-130 aircraft at the fuel leak queue, this result is not surprising.

Statistical Significance

A paired sample t-test was used to test the significance of the 1.93 day decrease in the C-141 mean. These calculations are shown in Appendix C. The results of the t-test indicate that the probability of obtaining a reduced mean using the heuristic is .91.

An F test was used to test the significance of the 81% decrease in the C-141 variance. These calculations are also shown in Appendix C. The

probability that the heuristic will decrease the variance of the C-141 time distribution is essentially one.

Conclusions

If the undesirable effects on other aircraft types are minimal as indicated, then the production manager can apply these scheduling heuristics and be highly confident of improving the situation at the depot. The significance tests show that with the proper heuristic, he can be 100% confident of decreasing the variance and 91% confident of decreasing the mean of the C-141 time distribution. Of course, knowing the proper heuristic implies knowing the optimal level of priority and knowing at which queues to apply the priority hearistic.

The results in Table I clearly indicate that performance does not always increase with level of priority. The C-141 aircraft statistics gradually improve as priority is increased until they peak at between thirty and forty days priority. Performance then declines with higher priority assignments but is much improved at infinite priority. A greater than sixty days priority, the results from the model become independent of the level of priority. The probability that a C-141 aircraft would be in the same queue with another aircraft type which had arrived sixty or more days earlier, is essentially zero for this depot model. Thus the C-141 would have infinite priority at all queues which employ the priority heuristic. A C-130 aircraft would only be serviced if no C-141 aircraft were in the same queue.

The results in Table I do indicate that application of the priority heuristic at all three common queues in addition to the SOT rule at the PDM/ACI queue is the best strategy for a given level of priority. These three common queues were chosen because they exhibited the longest waiting times. Thus the production manager, if he uses the above strategy, need

only find the optimal level of priority.

Recommendations

Using the same procedure used in this thesis, the production manager can find the optimal level of priority. Of course, the model used would have to be sufficiently tested to ensure validity. The model could be part of a routine which would input the present loading of aircraft at the depot and output the optimum priority assignment. Undesirable effects would be constrained by setting limits on the mean and variance of other aircraft types and excluding those priority assignments which exceed these limits. In this way the production manager could realize the potential of the priority scheduling heuristics.

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Appendix A

A-GERT Diagram of Model

Figures 5 through 9 are the complete Q-GERT flow chart for the model used in this thesis. The level of priority of the priority heuristic is specified by assigning values to the constants C_1, C_2, and C_3 in nodes 1, 6 and 11. The adjusted mark time is stored in attribute 10. Service times for the PDM/ACI portion of the process are stored in attribute 2. The SOT rule is applied at node 62. Refer to refrence 19 for complete meaning of all symbols used in diagram.

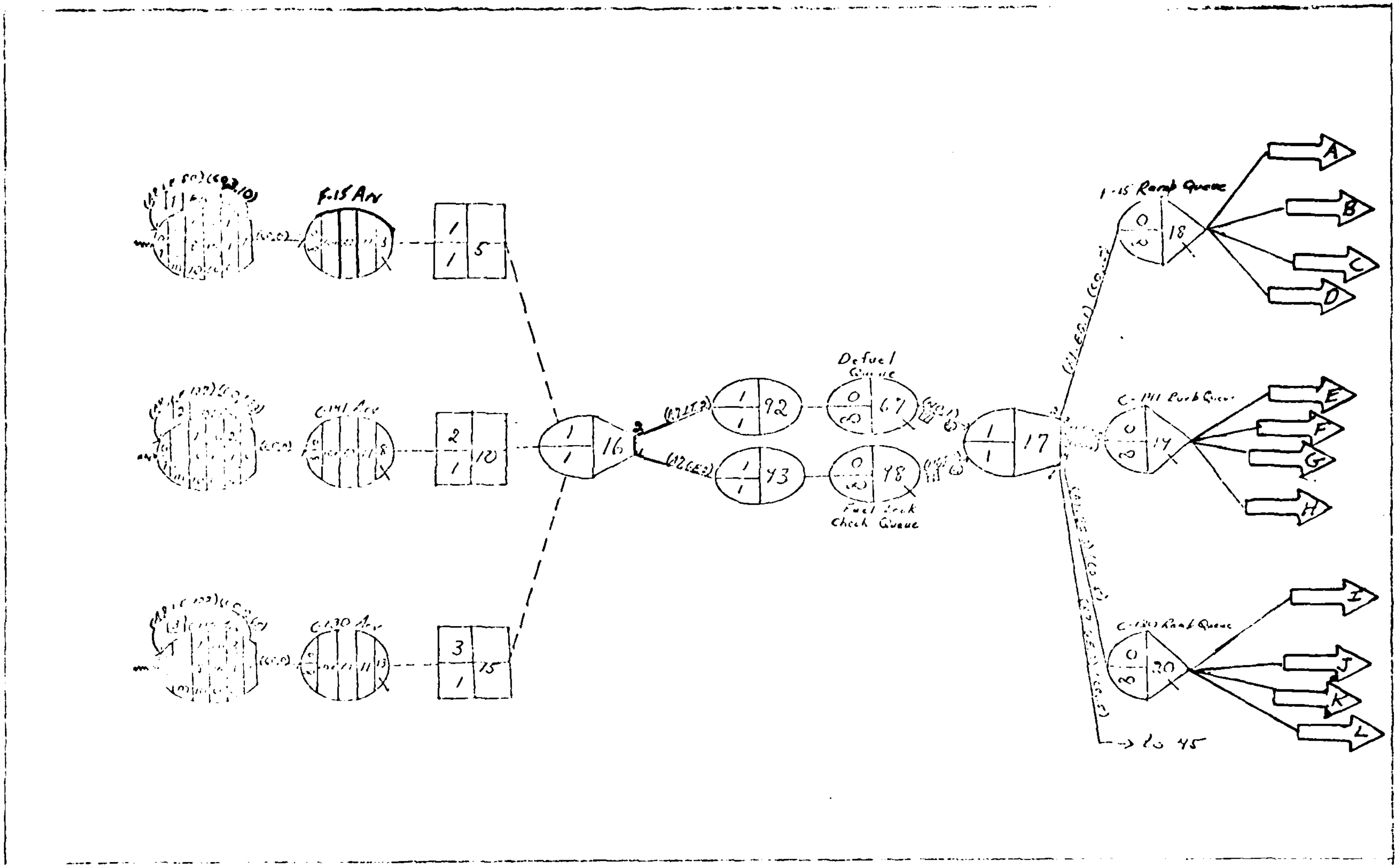

Fig 5. Q-GERT Diagram of Model

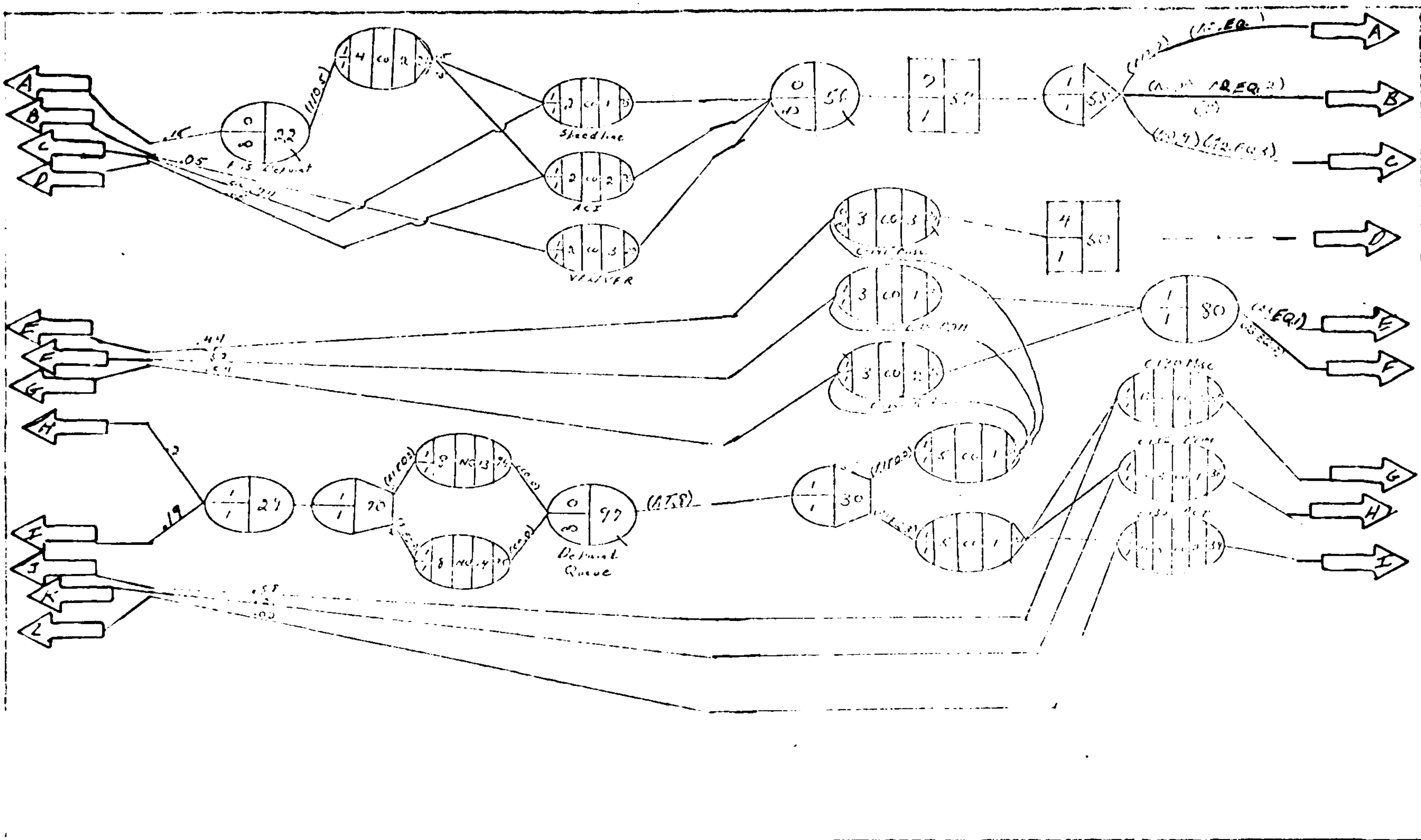

Fig 6. Q-GERT Diagram of Model (cont)

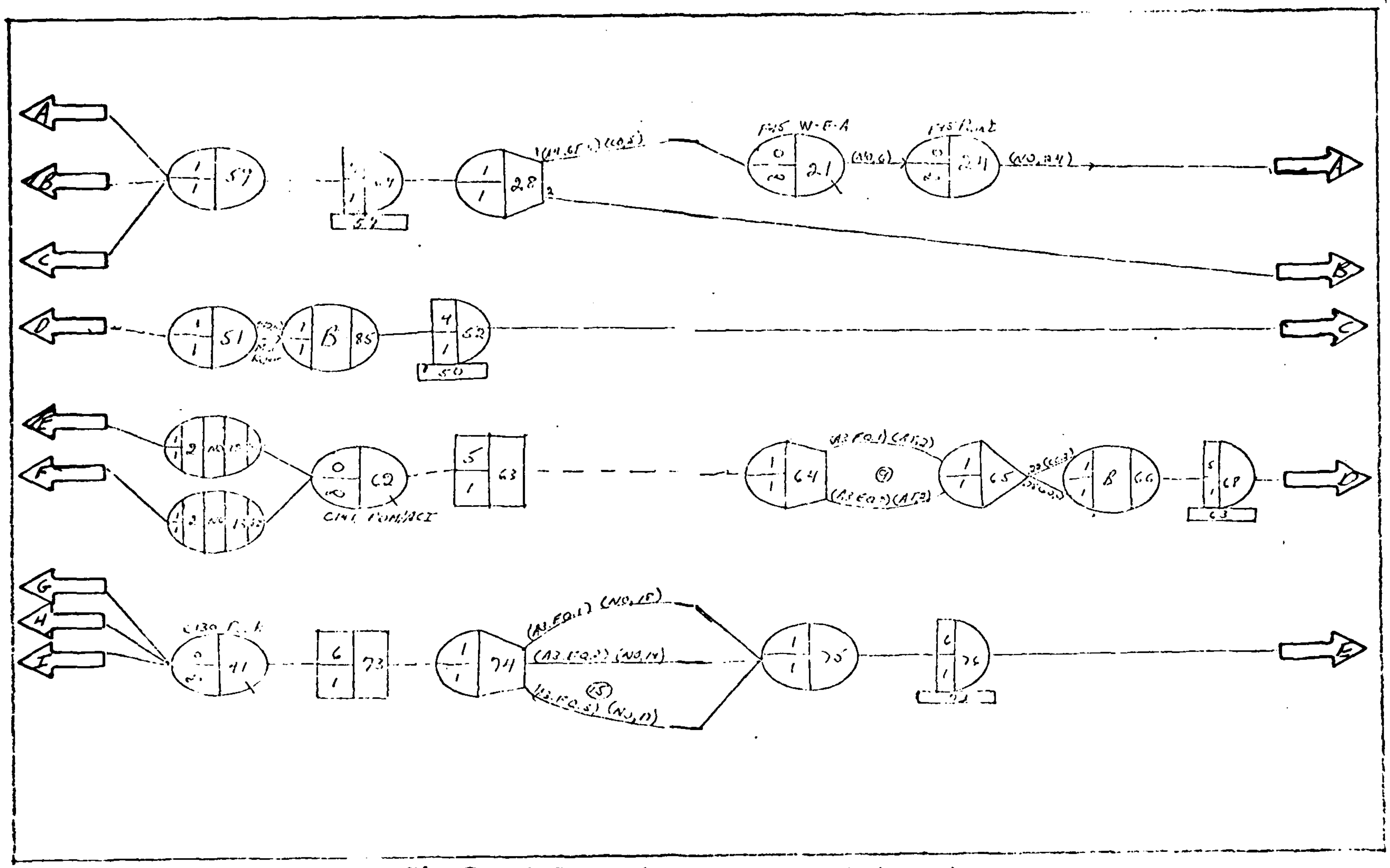

Fig 7. Q-GERT Diagram of Model (cont)

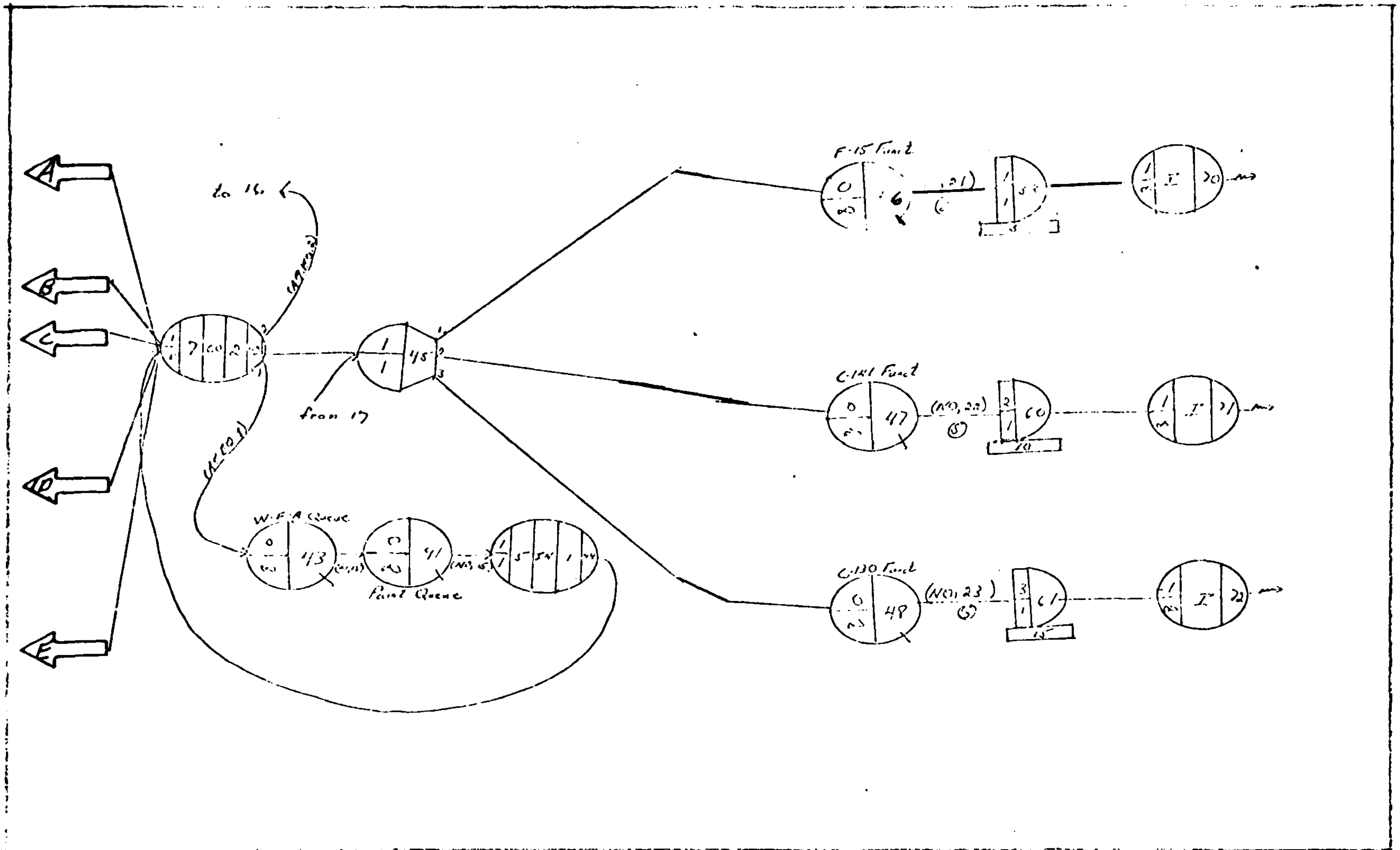

Fig 8. Q-GERT Diagram of Model (cont)

Appendix B

Program Code for Model

Figures 9 through 13 represent the program code used for testing the priority heruistic at a priority level of 10 days. The heuristic is assigned at the paint, depaint, and fuel leak check queues, and the SOT rule is applied at the PDM/ACI queue.

```
GEN,...,PLANNI...,1,1983,3,,1,327,...75,1,*
RES,1/F15...STA,12,5
RES,2/C1-15,24,10*
RES,3/C13...,30,13*
RES,4/C1-1MI...,2..5
RES,5/C1-1...4,12,...*
RES,6/C13...K,15,7...
RES,7/F1...K,12,5...
SOU,1,,1,4*
SOU,6,,1,4*
SOU,11,,1,4*
VAS,1,1,,1,3,IN,1*
ACT,1,1,,3.11,1/F15ARV,(9)A8.LE.105*
ACT,1,3*
QUE,3/F15ARV,(10)5*
ALL,5,,1,,3/16*
VAS,6,,,2,5,...,1,1,,,...
ACT,6,6,,1.33,2/C141AR,(9)A8.LE.179*
ACT,6,6*
QUE,6/C141ARV,(10)10*
VAS,8,1...,AT,11*
ALL,10,,2,,8/16*
VAS,11,,,3,...,IN,1,16,,403*
ACT,11,11,,2.65,3/C130AR,(9)A8.LE.122*
ACT,11,13
QUE,13/C130ARV,(10)13*
VAS,13,1...,AT,11*
ALL,15,,3,,13/16*
REG,16,,1,F*
REG,92,,1*
REG,93,,1*
ACT,16,92,(6)2,A7.LT.2.*
ACT,16,93,(6)1,A7.GE.2.*
QUE,67/RAMPDEF*
QUE,98/RAMPDEF*
ACT,67,17,NO,1,7/DEFUEL,+*
ACT,98,17,NO,20,7/FUEL LK,+
ACT,92,67*
ACT,93,93*
PAR,1,1.55,1.0,3.0,..62*
REG,17,,1,F*
ACT,17,45,,0.5,45/...AFT,,1,A7.GE.2*
ACT,17,18,,0.5,45,,2.A1.EQ.1*
```

Fig 9. Program Code for Model

```
ACT,17,19,,0.5,.7,,3.A1.E2.2*
ACT,17,2[illegible]0.5,[illegible],,[illegible],A1.E2.3*
QUE,18/F15 [illegible],,,[illegible]
ACT,15,2[illegible],,,[illegible]/F15,,0.15*
VAS,18,1,,1*
ACT,18,25,,,[illegible]F15,,0.7[illegible]*
ACT,18,27,,,[illegible]/F15,,0.0[illegible]*
ACT,18,2[illegible],,,[illegible]F15,,0.0[illegible]*
QUE,22/F15PT,,,,S/N
ACT,22,23,NO,[illegible],11/F15 PT*
QUE,24/F15PT,,,,S/N
ACT,24,[illegible]2,NO,2[illegible],15/F-15 PANT,1*
REG,23,,1,P*
ACT,23,25,,,15/PT TO CK,,0.5*
VAS,25,4,,2*
ACT,25,26,,,13/PT TO CK,,0.5*
REG,25,,1*
VAS,25,2,,1*
REG,27,,1*
VAS,27,2,,3*
REG,26,,1*
VAS,26,2,,2*
ACT,25,56*
ACT,27,55
ACT,26,56*
QUE,56/F15DOCK,(10)57*
ALL,57,,7,,55/58*
REG,58,,1,F*
ACT,58,59,NO,7,83/F15LOCK2,12,1,A2.E0.1*
ACT,58,59,NO,8,85/F15LOCK2,12,2,A2.E0.2*
ACT,58,59,NO,9,83/F15LOCK2,12,3,A2.E0.3*
REG,59,,1
ACT,59,69*
FRE,69,,7,,57*
ACT,69,28*
REG,28,,1,F*
QUE,19/C1-1R1F,,,F*
VAS,19,1,,2*
ACT,19,34,,,[illegible]/C1-1,,0.44*
ACT,19,35,,,[illegible]/C1-1,,0.32*
ACT,19,36,,,[illegible]/C1-1,,[illegible].[illegible]4*
ACT,19,29,,,[illegible]/C1-1,,0.20*
VAS,34,3,,3*
REG,35,,1*
VAS,35,3,,1*
REG,36,,1*
VAS,36,3,,2*
REG,29,,1*
ACT,29,90,,.5,9/TCEFT*
REG,90,,1,F*
```

Fig 10. Program Code for Model (Cont)

```
VAS,31,5,,1*
ACT,31,3,(3)35/C130,,0.9*
ACT,31,3,(3)35/C130,,0.05*
QUE,26/C13 MF,,,*
VAS,26,1,,*
ACT,26,35,(3)35/C130,,0.13
ACT,26,37,(3)35/C130,,0.53*
ACT,26,38,(3)35/C130,,0.32*
ACT,26,39,(3)35/C130,,0.21*
STA,37/C13MISC,,1,,*
VAS,37,3,,3*
STA,38/C13C PUN,,1,,*
VAS,38,3,,1*
STA,39/C13 ADI,,1,,0*
VAS,39,3,,2*
ACT,37,41*
ACT,38,41*
ACT,39,41*
QUE,41/C13 DOCK(1)73*
ALL,73,,2,,41/7*
REG,74,,1,*
ACT,74,75,NO,16,39/C13INWK,15,1,A3.EQ.1*
ACT,74,75,NO,19,39/C13INWK,15,2,A3.EQ.2*
ACT,74,75,NO,17,39/C13INWK,15,3,A3.EQ.3*
REG,75,,1*
ACT,75,76*
FRE,76,,2,,73*
ACT,76,42*
QUE,43/WA-ET-AL,,,,S/M*
ACT,43,91,NO,15,39/WA-ET-AL*
QUE,91/PAINT,,,,S/M*
ACT,91,44,NO,16,40/PAINT*
REG,44,,1*
ACT,44,42*
VAS,44,5,IN,1*
REG,42,,1,F*
VAS,42,7,,2*
ACT,28,42,(3)2*
ACT,23,21,,0.5,(6)1,44.GE.2*
QUE,21/F15WEA,,,,S/M*
ACT,21,24,NO,5,12/F15WEA*
ACT,42,10,(3)2,A3.EQ.2*
ACT,42,43,,1.0,(8)1,A3.EQ.1*
ACT,42,45,(3)3*
REG,45,,1,F*
ACT,45,46,(3)1,A1.EQ.1*
ACT,45,47,(3)2,A1.EQ.2*
ACT,45,48,(3)3,A1.EQ.3*
QUE,46/F15FUNCT*
QUE,47/C141FUNC*
```

Fig 11. Program Code for Model (Cont)

```
REG,34,,1*
VAS,34,3,NO,13*
REG,35,,1
VAS,35,,3,NO,14*
ACT,35,54,(8)1,A1.EQ.2*
ACT,35,53,(8)3,A1.EQ.3*
ACT,34,57*
ACT,35,57*
QUE,37/AIT UP,,,,3/M*
ACT,57,37,AT,3,39/CPTNW-E-A*
REG,36,,1,F*
ACT,36,55,NO,13,39,,2,A1.EQ.2*
ACT,36,31,NO,14,27,,3,A1.EQ.3*
REG,55,,1,F*
VAS,55,5,,1*
ACT,55,34,,,28/MISSORT,,0.1*
ACT,55,35,,,29/RCMPT,,0.79*
ACT,55,36,,,30/AIRCPT,,0.21*
QUE,34/C1+1MISS,(10)50
ALL,50,,4,,3*/
REG,51,,1*
ACT,51,35,NO,1,,18/MASSMX,20*
STA,65/C1+1MISC,,1,,*
ACT,65,52,(6)85*
FRE,52,,4,1,31*
ACT,52,,42*
REG,80,,1,F*
REG,81,,1*
VAS,81,2,NO,13*
REG,82,,1*
VAS,82,2,NO,11*
ACT,80,81,(8)1,A3.EQ.1.*
ACT,80,82,(8)2,A3.EQ.2.*
ACT,81,62*
ACT,82,62*
ACT,35,62,,,9*
ACT,36,62,,,17*
QUE,62/C1+1RPO1,,,,S/2,(10)63*
ALL,63,,5,,62/64*
REG,64,,1,F*
ACT,64,65,AT,3,20,9,1,A3.EQ.1*
ACT,64,65,AT,3,21,9,2,A3.EQ.2*
REG,65,,1,F*
ACT,65,66,,,22,,,.78*
ACT,65,66,,2,23,,0.22*
STA,66/C1+1INAK,,1,,65*
ACT,66,68,,,25*
FRE,68,,5,1,33*
ACT,68,42*
QUE,31/C1+1RPT,,,F
```

Fig 12. Program Code for Model (Cont)

```
QUE,46/C13CFUNT*
ACT,46,50,[illegible],21,42/F15FUNCT,6
ACT,47,5[illegible],22,45/C14[illegible]FUNC,5*
ACT,48,51,[illegible],23,44/C13,FUNT,5*
PRE,50,,[illegible],,1[illegible]*
PRE,[illegible]3,,1,,[illegible]*
PRE,51,,7,1,15*
ACT,50,71*
PAR,5,[illegible],1.5,[illegible]*
ACT,51,72*
STA,71/C141FUNT,,1,,1*
STA,7[illegible]/F15FUNT,,1,,1*
STA,72/C13CFUNT,,1,,1*
ACT,53,7[illegible]
PAR,5,1.[illegible],1.[illegible],2.[illegible],[illegible]*
PAR,7,22.5,14.[illegible],[illegible],4.10*
PAR,8,29.3,27.[illegible],34.[illegible],4.[illegible]4*
PAR,9,15.3,12.[illegible],20.0,5.34*
PAR,10,2[illegible].[illegible],23.[illegible],3[illegible],[illegible].46*
PAR,11,3[illegible].[illegible],14.[illegible],[illegible],7.63*
PAR,12,7[illegible].5,[illegible]4.[illegible],3[illegible].[illegible],5.11*
PAR,13,3.54,2.[illegible],7.[illegible],1.14*
PAR,14,3.4,2.[illegible],6.[illegible],1.[illegible]1*
PAR,15,1.25,1.[illegible],3.[illegible],[illegible].58*
PAR,16,5.17,3.[illegible],5.[illegible],1.49*
PAR,17,10.22,5.0,22.[illegible],4.09*
PAR,18,13.5,10.[illegible],21.[illegible],3.4*
PAR,19,23.[illegible],19.[illegible],31.[illegible],3.66*
PAR,2[illegible],2.1,1.,3.,[illegible]*
PAR,21,3.9[illegible],3.[illegible],17.[illegible],3.33*
PAR,22,7.45,3.[illegible],[illegible].[illegible],2.35*
PAR,23,7.3[illegible],[illegible].[illegible],16.[illegible],2.14*
PAR,24,2.19,1.[illegible],4.[illegible],0.59*
FIN*
```

Fig 13. Program Code for Model (Cont)

Appendix C

Sample Calculations

A paired smaple t-test was used to determine the significance of the change in the C-141 mean due to the heuristic which produced the lowest mean. The following calculations were involved in the test.

$$H_0: \mu_{Base} - \mu_{Heur} = \mu_d = 0$$
$$H_a: \mu_{Base} - \mu_{Heur} = \mu_d > 0$$
$$t = \mu_d / (\sqrt{S_d^2 / n}) = 1.37$$
$$t_\alpha = t_{.085} = 1.37 \xrightarrow{\text{Rej } H_0} .915 \text{ Significant}$$

The following calculations show how an F test was used to determine the significance of the change in the C-141 variance due to the heuristic which produced the lowest variance.

$$H_0: \sigma^2_{Heur} = \sigma^2_{Base}$$
$$H_a: \sigma^2_{Heur} < \sigma^2_{Base}$$
$$F = S_B^2 / S_H^2 = 5.218$$
$$F_\alpha = F_{.01} = 2.14 \xrightarrow{\text{Rej } H_0} .99^{+} \text{ Significant}$$

VITA

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Scheduling Heuristics
Aircraft Maintenence Depot

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Scheduling heuristics were applied to a model of the aircraft maintenence depot at Warner Robins Air Logistics Center. Since the C-141 aircraft was being overloaded into depot, heuristics which gave the C-141 priority were tested in an effort to reduce the mean and variance of the distribution of times the C-141 aircraft spent at the depot. One heuristic was found which reduced the average depot time by

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4%. The significance of this decrease was calculated to be 91%. A similar heuristic reduced the variance by 81%, with a significance of 100%. Thus, the potential exists for improving the flow of the overloaded C-141 aircraft through the depot, using scheduling heuristics.

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DATE